DEVELOPMENT OF A MULTIDISCIPLINARY APPROACH TO COMPUTE SUSTAINABILITY INDICES FOR SEMICONDUCTOR MANUFACTURING PLANT - A SINGAPORE PERSPECTIVE

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DECLARATION

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I hereby declare that this Project Paper is the result of my own work, except for quotations and summaries which have been duly acknowledged.

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ABSTRACT

Semiconductors are made of a solid crystalline material, usually silicone, formed into a simple diode or many integrated circuits. Semiconductor industries, which consumes large amounts of chemical and energy and large volumes of water, falls under the high hazard installation category in Singapore. Sustainability index computation and eventually benchmarking has not been studied for any privately listed companies in Singapore and in particular not studied for semiconductor manufacturing plants in Singapore. The objective of the study will be to determine the broad based parameters on sustainability indicators, determine the relationship between various parameters of sustainability, develop weightage factor for each parameters and develop a working model that will compute sustainability indices for semiconductor manufacturing environment in Singapore. Survey questionnaire was used and analysis of survey was done using known tools such as SPSS. Analytical hierarchy Process was used for computing weightage for the various parameters of sustainability. Based on the various models on sustainability, the proposed model involves four major constructs namely, management, employee wellbeing, resources and compliance. In the model chosen for this study, Sustainability index (SI) is a function of organization's wellbeing, (W), Resources (R), Compliance (C), and possession of a management system (M). Being a versatile decision making tool, Analytical hierarchy process (AHP) model was used to determine the weightage for each functional element. A simplified formula was computed for this study, which is SI = (0.375*Wellbeing+ 0.25*Compliance+ 0.25*Resource+ 0.125*Management)/5. SI for the two companies were deduced from the survey and substituting these values in the equation for SI, SI for company A was computed as 80% and for company B it was computed as 85%. This meant SI for company B was better than that of company A and that company B is less riskier than company A A working model thus was formed for sustainability indexing for semiconductor manufacturing plants in Singapore, which can be extended to other manufacturing plants in Singapore and region. Further the study can be improved by incorporating other parameters such as economics.

Key words: Sustainability Index, Resource, Compliance, Management, Wellbeing

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e) all respondents who participated in the survey

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LIST OF ABBREVIATIONS

AMOS	Analysis of a moment structures
AHP	Analytical Hierarchical Process
ASIC	Application - Specific Integrated Circuits
BSR	Business Social Responsibility
CERES	Coalition for Environmentally Responsible Economies
CFA	Confirmatory factor Analysis
CSD	Commission on Sustainable Development
CSR	Corporate Social Responsibility
DEA	Data Envelopment Analysis
DEAP	Distributed Evolutionary Algorithms in Phyton
DJSI	Dow Jones Sustainability Index
EPS	Earnings per share
EICC	Electronic Industry Citizenship Coalition
EnMs	Energy Management System
EnPIs	Energy Performance Indicators
EPA	Environmental Protection Agency, USA
EB	Environmental Burden
EMS	Environmental Management System
EnV-S	Environmental Value Systems Analysis
EFA	Exploratory Factor Analysis
FR	Frequency Rate
GRI	Global Reporting Initiative
GHG	Green House Gas
GTA	Green Technology Awards
GDP	Gross Domestic Product
GNP	Gross National Product
IChemE	Institution of Chemical Engineers
IC	Integrated Circuits
ISO	International Organization for Standardization
IUCN	International Union for Conservation of Nature
KMO	Kaiser - Meyer - Olkin
LEED	Leadership in Energy and Environmental Design
NEA	National Environmental Agency, Singapore
OHSAS	Occupational Health and Safety Assessment Series
ODS	Ozone Depleting Substances
PDCA	Plan - Do - Check - Act
PCA	Principal Component Analysis
QMS	Quality Management System

LIST OF ABBREVIATIONS (continued)

QMS	Quality Management System
3R	Reduce, Recycle, and Reuse
RoHS	Restriction of Harzardous Substances
SR	Severity Rate
SSIA	Singapore Semiconductor Industry Association
SS Awards	Singapore Sustainability Awards
SPSS	Statistical Package for the Social Sciences
SEM	Structural Equation Modelling
SSCM	Supply Chain Management
SBA	Sustainability Business Awards
SI	Sustainability Index
SD	Sustainable Development
TSMC	Taiwan Semiconductor Manufacturing Company
TBL	Triple Bottom Line Index
UPW	Ultra Pure Water
UNEP	United Nation Environment Programme
WEE	Wafer Edge Exposure
WBCSD	World Business Council for Sustainable Development
WEC	World Environment Centre
WRI	World Resource Institute

UNEP	United Nation Environment Programme
WEE	Wafer Edge Exposure
WBCSD	World Business Council for Sustainable Development
WEC	World Environment Centre
WRI	World Resource Institute

CHAPTER 1

INTRODUCTION

1.1 Introduction

The manufacture of any semiconductor requires an ultraclean environment, to ensure the purity of the semiconductor. This purity is vital; it helps ensure that the semiconductors act as a circuit at practically the atomic level. In fact, with device lines for many semiconductors now 0.18 microns wide (a micron is one-thousandth of a millimeter), a particle as small as 0.5 microns can completely destroy a circuit. A "cleanroom" is required for the production process. Clean room for semiconductors is maintained at various levels of cleanliness (dependent upon the semiconductors being made). Cleanroom are rated using the U.S. Federal Standard (Federal standards 1992) number 209E. Cleanroom are rated based on the number of airborne particles of size 0.5 microns or larger in a standard cubic foot of air. For example; a Class 1 clean room will have no more than one particle per cubic foot that is larger than 0.5 micron. Clean rooms are rated as class 1000, class 100 or class 10 or better.

Global semiconductor industry (semicon, 2013) revenue is expected to grow 6.4 percent in 2013 to $322.30 billion. The projected revenue growth in 2013 tracks with an expected 4.6 percent increase in silicon demand to shipments of 9.55 billion square inches, compared to 9.12 billion square inches in 2012r and 9.16 billion square inches in 2011.

The Semiconductor industry Association (SIA, 2017) projects the industry's worldwide sales will be $408.7 billion in 2017. This would mark the industry's highest-ever annual sales, its first time topping $400 billion, and a 20.6 percent increase from the 2016 sales total.

Within the electronics industry there are two major branches; the components industry which includes the semiconductor manufacturing, and the consumer electronics industry which includes the television manufacturing. The semiconductor industry can further be divided into the still broad memory chips, and the microprocessors industry. Memory chips are chips which has the sole purpose of containing and the storing of its pre-programmed information. Microprocessors interpret, control and carry out all the instructions that are expected by the user. Semiconductor parts are used in a wide range of ways, which, for the sake of simplicity, can be divided into two major categories also; the electronic equipment and the consumer electronics sector. Within the electronics sector there is much overlap, mostly because of the computer. Computers can be used in many areas such as in the industry, where it was originally used. Later computers, when they were started to be sold to the public through retailers. From then on computers became a very common thing, until the current state, where virtually all households in the developed world own a computer. Since billions of computers are being sold all over the world today, and given the fact that all computers need a processor, billions of semiconductors are being sold today to the public only. Both the consumer and the semiconductor, but especially the semiconductor industry is very capital intensive industries, which mean that a lot of money is required just to start the company. Their Research and development (R&D department are very labour intensive and knowledge based industries. At the same time, mostly in the United States of America, the every day and routine type of activities is left to the smaller corporations to carry out. We will see that the global distribution, and also the degree to which the different developed countries are involved in the industry.

All electronic components are discrete devices (Muller, 1986). There are six major types of semiconductors, each with different patterns of demand:

a) Standard devices: they are standardized and can be used in a wide variety of ways.

b) Exclusive devices: these are basically the same as standardized devices with the difference that these devices can only be produced by a couple of producers only, as they have technological monopoly on the particular semiconductors.

c) Specific devices: these are also mass produced, but unlike the previous two, can only be used in a certain way.

d) Custom devices: these are manufactured for a certain user and according to the user requirements.

e) Microprocessors: they can be mass produced, but can be programmed for specific purposes.

f) Semicustom devices: certain parts of these semiconductors can be mass produced, and later the final connections will be arranged according to the requirements of the user. These are a little like microprocessor. These devices are also known as "application-specific integrated circuits (ASICs) and the demand for these semiconductors are expanding exceptionally and rapidly.

During the manufacture of semiconductors, there are two things that have to be considered especially are:

a) The "yield" of manufacturing process: decreasing the number of faulty circuits, and

b) To increase number of circuits on a chip.

Mainly, these two factors are due to the steep increases in the cost of setting up a semiconductor manufacturing plant. Besides the fact that as the number of circuits on a chip increases, it is also a trend to increase the spending on a larger and more and more modern plant, be more capital and research intensive.

There are different types of semiconductor producing firms (Kaeslin, 2008). The three broad categories are:

a) Vertically integrated captive producers: they manufacture the semiconductors entirely for their own use.

b) Merchant producers: these firms produce all their semiconductors to sell them to other companies.

c) Vertically integrated captive-merchant producers: they produce semiconductors partly for themselves and partly for other companies.

American firms tend to fall into one of the first two categories, whereas, Japanese and European producers are of the third categories. These Japanese and European producers are firms that are large electronic consumer products producing firms that operate in a wide range of spectrum. Generally the trend was that semiconductor producing firms started to produce consumer goods, and the consumer electronic producers started to produce semiconductors, both, for their own use and also for sale. Finally there were semiconductor researching firms, called “fabless” companies that did not have a manufacturing capability, rather what they researched out; they sold to actual producer of semiconductors. In the 1990s, because of shortages in the production capacity, they were forced to actually start producing either by partnering up by an already producing firm or to build a plant on their own. Usually the previous was the case.

1.2 Characteristics and Processes of Semiconductor industry

Semiconductors are made of a solid crystalline material, usually silicone, formed into a simple diode or many integrated circuits. A simple diode is an individual circuit that performs a single function affecting the flow of electrical current. Integrated circuits combine two or more diodes. Up to several thousand integrated circuits can be formed on the wafer, although 200-300 integrated circuits are usually formed. The area on the wafer occupied by integrated circuits is called a chip or dies. The process (Kaeslin, 2008) has been broken down into three major steps:

a) Step 1 - Design - As with any manufacturing process, the need for a particular type of product must be identified and process specifications must be developed to address that need. In the case of semiconductors, the circuit is designed using computer modeling techniques. Computer simulation is used to develop and test layouts of the circuit path. Then, patterning "masks," which are like stencils, are fabricated, manufacturing equipment is selected, and operating conditions are set. All of these steps occur prior to actually producing a semiconductor.

b) Step 2 - Crystal processing - Wafers, which consist of thin sheets of crystalline material, are the starting point of semiconductor production. Silicon, in the form of ingots, is the primary crystalline material used in the production of 99 percent of all semiconductors. Silicon crystals are actually "grown" using controlled techniques to ensure a uniform crystalline structure. Because crystals of pure silicon are poor electrical conductors, controlled amounts of chemical impurities or dopants are added during the development of silicon ingots to enhance their semiconducting properties. Dopants are typically applied using diffusion or ion implantation processes. Dopants eventually form the circuits that carry the flow of current. Other processes in crystal processing includes:

- Diffusion_is a chemical process which exposes the regions of the silicon surface to vapors of the metal additive (dopant) while maintaining high temperatures.
- Ion implantation_is a process that allows for greater control of the location and concentration of dopants added to the wafer. Metal dopants are ionized and accelerated to a high speed. The ions penetrate the silicon surface and leave a distribution of the dopant. Either doping process can be used in semiconductor manufacturing. Antimony, arsenic, phosphorus, and boron compounds are the

dopant materials most commonly used for silicon-based semiconductors. Other dopants include aluminum, gallium, gold, beryllium, germanium, magnesium, silicon, tin, and tellurium. Wastes including antimony, arsenic, phosphorus, and boron may be generated in the wastewater as a result of ion implantation or diffusion. Excess dopant gases, contaminated carrier gases, and out-gassed dopant gases from semiconductor materials may also be generated. Most semiconductor manufacturers obtain single crystal silicon ingots from other firms. Ingots are sliced into round wafers approximately 0.76 mm (0.03 inches) thick and then rinsed. The wafers are further prepared by mechanical or chemical means. A wafer's surface may be mechanically ground, smoothed, and polished, as well as chemically etched so that the surface is smooth and free of oxides and contaminants. Chemical etching removes organic contaminants using cleaning solvents and removes damaged surfaces using acid solutions. Chemical etching is usually followed by a demonized water rinse and drying with compressed air or nitrogen. In some cases, bare silicon wafers are cleaned using ultrasound techniques, which involve potassium chromate or other mildly alkaline solutions. Etching is a method of cutting into, or imprinting on, the surface of a material. Several etching processes can be used on semiconductors, as well as integrated circuits and printed wiring boards. Wet etching uses acid solutions to cut patterns into the metal. Dry etching involves reactive gases and is rapidly becoming the method of choice for high resolution. Dry etching processes use various halogenated or non-halogenated gaseous compounds. In the semiconductor industry, dry plasma etching, reactive ion etching, and ion milling processes are being developed to overcome the limitations of wet chemical etching. Dry plasma etching, the most advanced technique, allows for etching of fine lines and features without the loss of definition. This process forms plasma above the surface to be etched by combining large amounts of energy with low pressure gases. The gases usually contain halogens.

Materials used during the wet etching process may include acids (sulfuric, phosphoric, hydrogen peroxide, nitric, hydrofluoric, and hydrochloric), ethylene glycol, hydroxide solutions, and solutions of ammonium, ferric, or potassium compounds. Materials used during the dry etching process may include chlorine, hydrogen bromide, carbon tetra fluoride, sulfur hexafluoride, trifluoromethane, fluorine, fluorocarbons, carbon tetrachloride, boron trichloride, hydrogen, oxygen, helium, and argon. Typical solvents and cleaning agents include acetone, demonized water, xylene, glycol ethers, and isopropyl alcohol. The most commonly used cleaning solution in semiconductor manufacturing includes a combination of hydrogen peroxide and sulfuric acid. Acid fumes and organic solvent vapors may be released during cleaning, etching, resist drying, developing, and resist stripping operations. Hydrogen chloride vapors may also be released during the etching process.

c) Wafer fabrication, layering and Assembly - Wafers are usually fabricated in batches of 25 to 40. Wafer preparation begins with an oxidation step.

- Oxidation_is a process in which a film of silicon dioxide is formed on the exterior surface of the silicon wafer. Thermal oxidation takes place in a tube furnace with controlled, high temperatures and a controlled atmosphere. Oxidation is a reaction between the silicon wafer surface and an oxidant gas such as oxygen or steam. This process may be needed as a preliminary step before diffusion or ion implantation (doping). This layer protects the wafer during further processing. Following oxidation, the wafer surface is thoroughly cleaned and dried. Materials used during oxidation, include silicon dioxide, acids (hydrofluoric), and solvents. Materials such as oxygen, hydrogen chloride, nitrogen, trichloroethane, and trichloroethylene may also be used. Wastes that may be generated from this process include: organic solvent vapors from cleaning gases; rinse waters with organic solvents from cleaning operations; spent solvents; and spent acids and solvents in the wastewater.

- Next, patterns are imprinted onto the substrate using photolithography (also referred to as lithography) and etching processes. Photolithography is the most crucial step in semiconductor manufacturing because it sets a device's dimensions; incorrect patterns affect the electrical functions of the semiconductor. Photolithography is a process similar to photo processing techniques and other etching processes in that a pattern is imprinted. The silicon wafer is coated uniformly with a thin film of resist. A glass plate or mask is created with the circuit pattern, and the pattern is imprinted in one of several ways. One type of optical photolithography is the projection of x-rays through a special mask close to the silicon slice. Another type of optical photolithography, one that does not need a mask, is electron-beam direct patterning, which uses a controllable electron beam and an electron sensitive resist. Once the pattern is developed, some areas of the wafer are clear and the rest are covered with resist. Two types of photo resists can be used during semiconductor production:
- Positive_photo resists are chemicals that are made more soluble, with regard to a solvent (i.e., developer), after exposure to radiation. During development, the developer removes the resist that was exposed to radiation.

- Negative photo resists are chemicals that polymerize and stabilize upon exposure to radiation. During development, the developer removes the resist that was protected from radiation.
- After photolithography, chemical developers are used to remove unnecessary coatings or resist material that remains on the substrate. Development can be conducted by liquid methods (dip, manual immersion, or spray coating) or dry methods (plasma). The wafer is then etched in an acid solution to remove selected portions of the oxide layer to create depressions or patterns. The patterns are areas in which dopants will be applied. The wafer is rinsed, typically by immersing in a stripping solution to remove unwanted photo resist, and then dried.

Many toxic materials are used in the wafer fabrication process (CNET, 2002) these include:

a) Poisonous elemental dopants, such as arsenic, antimony, and phosphorus.
b) Poisonous compounds, such as arsine, phosphine, and silane.
c) Highly reactive liquids, such as hydrogen peroxide, fuming nitric acid, sulphuric acid, and hydrofluoric acid.

It is vital that workers not be directly exposed to these dangerous substances. The high degree of automation common in the Integrated Circuits (IC) fabrication industry helps to reduce the risks of exposure. Most fabrication facilities employ exhaust management systems, such as wet scrubbers, combustors, heated absorber cartridges, etc., to control the risk to workers and to the environment.

The chemicals that are released in the greatest quantity by the electronics/computer manufacturing industry include Acetone Ammonia Dichloromethane Freon 113 Glycol Ethers Methanol Methyl Ethyl Ketone Sulfuric Acid Toluene Trichloroethylene Xylene (AEA 2004).

The energy and water demands placed on natural resources in order to produce semiconductors are significant. As the complexity and size of the semiconductor facilities (known as fabs) have grown, so have these demands. New facilities can use 30 to 50 megawatts of peak electrical capacity enough to power a small city. Energy is not the only commodity in high demand for semiconductor facilities. New wafer Semiconductors and integrated circuit manufacturing plants can consume millions of gallons of water every day, enough to supply several thousand households. The growth will continue to have an impact on the resources of the US Pacific Northwest. Industry projections for the next decade indicate an annual energy requirement of between 400-500 megawatts of additional electricity from Northwest power suppliers - an electricity demand approximately equivalent to two new natural gas-fired power plants, and up to 2 percent of the Northwest's current average annual electricity load. Energy and water inputs should not be viewed separately for semiconductor manufacturing. Water use is inextricably linked to energy use. Water operations, from pumping water through the plant, to making the Ultra Pure Water (UPW) necessary for semiconductor manufacturing requires a great deal of energy.

1.3 Sustainability factors in world economic scene

Growing business recognize sustainability as an important concept for survival in the competitive world. Sustainability has become a widely acknowledged key objective to incorporate into the daily operations of companies and organizations.

Sustainability indicators are able to transform large value of information about complex manufacturing environment into concise, policy-applicable and manageable information. Most sustainability indices include indicators based on what they seek to measure and what they would report to their target audience. Most sustainability indices develop industry-specific scores or indices. In this way, best accounts for diversity issues are covered within “sustainability” and the manner in which these issues are critical, or less important, to a specific sector. The sector specificity of ratings may be more beneficial than a highly generalized and universally applicable rating system.

The manufacturing of electronic products can have significant impact on the environment. From the use of rare materials to energy and water demands of manufacturing processes, there is a clear need for electronics companies to employ and promote environmentally responsible practices in the electronics supply chain.

The Electronic Industry Citizenship Coalition - EICC (EICC 2014) created a standard approach to measuring and reporting carbon emissions in the global electronics supply chain. Based on global standards such as the World Resource Institute's (WRI) Greenhouse Gas Protocol (Greenhouse 2014) and EICC Carbon Disclosure Project as Carbon Reporting System was launched. Using this tool, companies can measure and share emissions data with their customers in a standardized template. The platform integrated a standardized questionnaire for gathering quantitative carbon emissions and energy data, as well as qualitative information on carbon and energy management practices.

Further in a 2009 study from consultant A.T. Kearney (kearney, 2011) found that during the economic slowdown, companies that were recognized as being “sustainability-focused” outperformed others in their industries by an average of 15% over six month.

Different sustainability index are currently used across the world. Some are country wide, continent wide and some are company specific. Dow Jones Sustainability Index (DJSI) focuses on countries and continents. Robecosam, US based organisation compiles annual Sustainability yearbook, in which more than 2000 companies are assessed, from more than 3000 companies who are invited to do the assessment. DJSI computation based on over 340 corporations and includes semiconductor companies such as Advanced Semiconductor Engineering Inc, ASML Holding NV, SK Hynix Inc., ST Microelectronics NV, Tokyo Electron Ltd, United Microelectronic Corp, Samsung Electronics Co. Ltd., Taiwan Semiconductor

Manufacturing Company (TSMC), and Samsung Electronics, Intel Corporation. TSMC (TSMC 2012) scored highest in categories including Risk and Crisis Management, Supply Chain Management, Environmental Policy/Management System, Product Stewardship, Water-Related Risk, Human Capital Development, Labour Practice Indicators and Human Rights, and Stakeholder Engagement. The Corporate Sustainability Assessment by Robesco (unit of Dow Jones Sustainability Indices) forms the foundation of integration and allows to proactively engaging companies on sustainability topics that drive business performance and help them manage long-term risks. Sustainability forms the core of our investment philosophy, and we are driven to help companies make it part of their corporate DNA (DJSI). Most of the data on sustainability index has been for public listed companies.

Presently there are no sustainability index computation and no benchmarking for semiconductor wafer manufacturing plants in Singapore on sustainability.

1.4 Problem Statement

As the concept of sustainability has grown more importantly, many companies are discovering a need to measure, track and compare their efforts in this area. Indices developed for use by mutual funds and other investors provide a financially-oriented picture. But until now, executives and business managers in private sector didn't have a tool for managing the sustainability performance of their firm's business lines.

It is important to not only understand what impacts are relevant to an organization, but it is equally important to understand the trade-offs between different decisions. Organizations often define a set of metrics to help manage complex decisions. Managing sustainability decisions should be no different. One tool that is useful for managing these types of complicated decisions is Sustainability Index. A sustainability index is meant to simplify the complex decision-making process that will help company to become more sustainable. Cascading this information down to a manageable set of decision criteria can greatly minimize this complexity. The idea behind a sustainability index is to aggregate the relative information about the sustainability aspects of various decisions, strategies, and approaches, and then provide an easy-to-understand “scoring” system to quickly determine the most sustainable options.

Semiconductor manufacturing plants employs large workforce. Singapore with its limited water resources has been promoting sustainable manufacturing. As briefly explained in section 1.2, Semiconductor industries, which consumes large amounts of chemical and energy and large volumes of water, falls under the high hazard installation category in Singapore. Sustainability index has always been a challenge to measure for semiconductor plants especially for privately listed companies. Singapore companies are yet to adapt to sustainable practices in total.

Sustainability index computation and eventually benchmarking has not been studied for any privately listed companies in Singapore and in particular not studied for semiconductor manufacturing plants in Singapore. All semiconductor manufacturing plants are privately held and are not publicly listed in Singapore.

1.5 Aim of the Study

This research study aims to:

a) analyze the current sustainability models used globally

b) identify parameters that would be used for computing sustainability index in a typical privately listed semiconductor manufacturing plants

c) develop sustainability index for a typical semiconductor wafer fabrication manufacturing plant and

d) benchmark against similar industry with a Singapore perspective

1.6 Research Questions and Objectives of the Study

1.6.1 Research Questions

Based on the research statements presented above, therefore there is a need to identify sustainability indicators and to study the impact of these indicators for sustainability benchmarking in the Singapore semiconductor manufacturing environment.

The sustainability indicators vary from sector to sector and have no uniform parameters in Singapore. In order to confirm these contentions, the following research questions emerge:

a) What are the parameters experienced by semiconductor manufacturing plants in Singapore that contribute to sustainability?

b) What are the most suitable sustainability indices model?

c) What are benchmarking models that can be used for sustainability index?

d) How are sustainability benchmarked in the world and how can these indices be adopted to semiconductor manufacturing environment in Singapore?

1.6.2 Objectives of the Study

The objective of the study are as follows:-

a) To determine the broad based parameters on sustainability indicators

b) To analyze the scientific literature on the various Sustainability models

c) To establish and validate relationship between various criteria of sustainability and

d) To develop a working model that will compute sustainability indices for semiconductor manufacturing environment in Singapore

1.6.3 Conceptual Model

Data to be obtained for the study will include questionnaire related to the performances of occupational safety and health, environmental, energy, corporate social responsibility and management system. The study will not focus on the economic indicators for sustainability index, due to its varied market conditions. And limited information availability from companies Sustainability index computation will involve decision making models like Analytical Hierarchical Process (AHP). AHP stands better for this study compared to other decision making models such as Rational, Social, and Decision Tree. The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions in situations such as Rankings. Advantage of using AHP mode. AHP is a proven tool, designed for multi criteria, easy to use and builds alignment around criteria priorities. By quantifying the essential criteria, the final decision is often easier to see than simply trying to make sense of varying levels of importance and preference alone.

1.7 Significance of the Study

Sustainability assessment is commonly viewed as one of the impact assessment process tools. Companies are increasingly coming under strong global pressure to incorporate sustainability considerations into their manufacturing activities. Although quite a few private sector companies understand that sustainability should be integrated into their business models, the integration of sustainability as such and especially the assessment towards establishing sustainability index remain a complex and open issue. Hence, there is a need to develop a tool that would allow quantifying and creating an index for sustainability of a semiconductor manufacturing environment. Taking into account the fact that sustainability indicators applied worldwide use different domains, this research study will develop a composite sustainability index to assess the sustainability of a manufacturing environment. The semiconductor industry was chosen for research purposes.

There is an urgent need to integrate environment, energy, material resource, employee wellbeing, resources, and management system performances. Presently there is no universal performance indicator that integrates these indices. In a survey conducted in 2017 (Lee Meixian, 2017), 26 percent of the Micro and Medium Enterprises (MME) respondents in Singapore, mention that Sustainability as one of the three long term objectives.

Present research work attempts to develop a sustainability index model applicable for semiconductor manufacturing plant. The use of a set of corporate governance, occupational health and safety performance indicators, and environmental principles will be an important element in the sustainability indices computation.

Research of the proposed topic would enhance the value of the semiconductor industry and would ensure the products and services are produced from a sustainable manufacturing site. This benchmarking would set a standard for companies to understand their risks and the ability to sustain in the industry besides looking into energy and environment. The present research would focus more on one layer of the semiconductor industry and this model from this research can be extended to other industrial sectors across the globe.

1.8 Scope of the Study

The scope of the study is to:

a) Identify sustainability indicators or parameters
b) Compute sustainability index
c) Compute a working model and potentially benchmark sustainability indices for semiconductor wafer fabrication manufacturing plants in Singapore.

Research study and analysis has been carried out in the semiconductor manufacturing plants in Singapore. Presently there are ten (10) wafer fabrication semiconductor manufacturing plants in Singapore.

1.9 Thesis outline

1.9.1 Introduction

Many toxic materials, larger quantities of water are used in the wafer fabrication process of a semiconductor industry. Large quantities of air emissions and wastewater discharge are common with semiconductor industries, there is no universal definition for sustainability that can be applied for all situations, however, sustainability potentially means a measure to endure or sustain. Sustainability index computation is currently not available for privately listed companies in the world.

1.9.2 Literature Review

Primary source of literature review is from books, journals, magazines, newspaper and articles in websites. Dow Jones Sustainability Index (DJSI) is one of the models used for public listed companies in USA with primary focus for listing in stock market. Many other models have identified sustainability index on sector based such as environmental sustainability. Most models on sustainability consider factors such as economic, social, environmental, employee wellbeing, and governance. In Singapore, a survey conducted in 2017shows Singapore firms is still slow to adopt sustainability practices. There is no single sustainability index model developed for privately listed semiconductor companies.

1.9.3 Objectives of the study

The key objectives of this study as mentioned in section 1.6 are to determine the broad based parameters on sustainability indicators, and develop a working model that will compute sustainability indices for semiconductor manufacturing environment in Singapore.

1.9.4 Research Methodology

Survey questionnaire will be used and analysis of survey was done using known models such as SPSS. Analytical hierarchy Process model is used for computing weightage for the various parameters of sustainability. Based on the various models on sustainability, the proposed model involves four major constructs namely, management, employee wellbeing, resources and compliance.

1.9.5 Data Collection, Results and Analysis

Primary source of data collection involves literature reviews and survey in the form of questionnaires. AHP model was used to determine the weightage of the four constructs while based in the survey, individual scoring from each semiconductor company was determined. Sustainability index (SI) formula was used to determine the sustainability index for each company. SI was then compared with similar company and benchmarking conducted.

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Development of a multidisciplinary approach to compute sustainability index for manufacturing plants - Singapore perspective

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Abstract

The purpose and objectives of this paper is to determine the determinants for computing sustainable footprint for a typical semiconductor manufacturing facility and subsequently to benchmark the sustainability footprint with other semiconductor manufacturing environment. Sustainability index studies have been used by different agencies mostly for public listed companies. Suitable checklist was used to determine the sustainability index of an organization and the results were compared with other similar organization. Using one approach, sustainability index was computed and compared with the other similar organization. By computing the sustainability index for a manufacturing organization, it will help the organization to identify the areas to improve for more sustainable operations. Sustainability index is a function of wellbeing, management, resource and compliance. By using Analytical Hierarchic Process (AHP) model a simple Sustainability index formula was developed for this study SI = (0.375*Wellbeing +0.25*Compliance+0.25*Resource+0.125*Management)/5, Using a structured questionnaire and giving a scoring for each construct, SI for a manufacturing company was computed. For one of the company, Sustainability Index was computed as 80%. Benchmarking can be done with similar industrial sector and will also help shareholders and other interested parties to know better of the organization in terms of their ability to be sustainable. Organizations with low sustainable index will be preferred and will be better recognized in the market. This paper has attempted to define sustainable index and also a method to compute sustainability Index (SI) for a manufacturing organization in Singapore.

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I. INTRODUCTION

The manufacture of any semiconductor requires an ultraclean environment, to ensure the purity of the semiconductor. Many toxic materials are used in the fabrication process (CNET, 2002) These include poisonous elemental dopants, such as arsenic, antimony, and phosphorus, Poisonous compounds, such as arsine, phosphine, and silane, highly reactive liquids, such as hydrogen peroxide, fuming nitric acid, sulphuric acid, and hydrofluoric acid. The chemicals that are released in the greatest quantity by the electronics/computer manufacturing industry.

The energy and water demands placed on natural resources in order to produce semiconductors are significant. As the complexity and size of the semiconductor facilities (known as fabs) have grown, so have these demands. New facilities can use 30 to 50 megawatts of peak electrical capacity enough to power a small city. Energy is not the only commodity in high demand for semiconductor facilities. New wafer Semiconductors and integrated circuit manufacturing plants can consume millions of gallons of water every day, enough to supply several thousand households. Water use is inextricably linked to energy use. Water operations, from pumping water through the plant, to making the Ultra Pure Water (UPW) necessary for semiconductor manufacturing requires a great deal of energy. Growing business recognize sustainability as an important concept for survival in the competitive world.

A universally accepted definition of sustainability is elusive at this point. Sustainability is the capacity to endure. Most of the research models (Dow Jones, 2016) on sustainability highlighted the relationships among energy (GRI, 2015), environment, finance, social aspects and governance, especially among those companies where access to company's financial data is available (Ethos, 2005). Following Table 1 is the summary of various relating to sustainability performances and indicators:

Table -1 Summary of sustainabilty indeices used by various agecies

S/N	Agency and Country	Indicator/Indices
1	Sustainable development (SD) strategy, UK	• Environmental Limits • Healthy and just society • Sustainable economy • Sound Social responsibly • Good governance
2	Sustainable Development of the Commission on Sustainable Development (CSD).	• Social • Environmental • Economic and • institutional
3	Dashboard of Sustainability	• economic • social and • environmental issues
4	The Barometer of Sustainability. Developed by IUCN,	• human and • environmental wellbeing
5	Global Reporting Initiative (GRI).	• economic 6environmental and • social need
6	The Sustainability Metrics of the IChemE	• environmental responsibility, • economic return and

		• social development
7	The Dow Jones Sustainability Index (DJSI)	• Economic • Environmental and • social developments
8	The Triple Bottom Line Index (TBL	• financial growth • ecological improvement, and • ethical equity
9	ISO standards on Sustainability	• ISO 14001 - focussing n environmental management • ISO 50001 - focussing on energy management • ISO 21929-1:2011 - fussing on sustainability in construction - establishes a core set of indicators including environmental, economic and social indicators • ISO 21930 - Sustainability in building construction - Environmental declaration of building products
10	Singapore Guidelines on Sustainability	• Economic, Social • Environemnt and Value creation

For a manufacturing organization to be sustainable, the organization need to take care of the wellbeing of their working capital (employees), preserve and conserve resources, have corporate governance and social responsibility and have sound management system.

The key objective of this study is to evaluate the sustainability index for a typical manufacturing industry in Singapore and includes:

1. determining the broad based parameters on sustainability indicators
2. arriving at selection criteria for benchmarking semiconductor companies in Singapore
3. establishing and validating relationship between various criteria of sustainability and
4. developing a working model that will compute sustainability indices for semiconductor manufacturing environment in Singapore

II. RESEARCH METHODOLOGY

A conceptual model was developed for this study For privately listed companies in Singapore, getting economic information is not possible. Thus, only four parameters or constructs were identified as Sustainability index parameters for this study. These include: Management, Wellbeing, Compliance and Resources.

Baaed on the theoretical framework developed for this study, Sustainability Index (SI) is a function of Wellbeing, Resource, Compliance and Management. Expressing the same in equation,

SI = f (W, R, C, M) ....Equation 1

where SI = Sustainability Index, W = Wellbeing, R = Resources, C = Compliance and M = Management
Perception survey was conducted among semiconductor companies to identify the key importance affecting the organization for these four constructs. Top four concerns or issues were identified as the sub-components for these four construct. A 7 step Analytical Hierarchy Process (AHP) model was used to develop the weightage to be given for each construct. Table 2 provides the summary of weighatage identified for the four construct.

Table 2 -Weightage factor using AHP model

NORMALIZED MATRIX	priority vector	Round-off Values
Resource	25%	25%
Compliance	25	25%
People Wellbeing	37.5	37
Management	12.5%	13%
sum	100.0%	

Using the weightage factor developed using AHP model, Sustainability Index in equation 1 can be rewritten as

SI = (0.375*Wellbeing +0.25*Compliance+0.25*Resource+0.125*Management)/5 ....**Equation 2**

where, 5 is the common denominating factor as every construct has five sub components.

A structured questionnaire was prepared for three set of respondents –heavy manufacturing companies, Consultants and professionals in the industry. Follow-up telephone calls were made directly to the personnel responsible for energy and environmental management to confirm receipt of the questionnaire and to remind them of the survey. In some cases the questionnaire was faxed again to facilitate immediate response. A total of 40 respondents were contacted, of which 25 responded. The Structured questionnaire was used for this purpose.

III. RESULTS AND DISCUSSION

The structured questionnaire was completed with the semiconductor company. Each of the answers with 'yes' was given a score of 1 and each answer with 'no' was given a score of 0. Table 3 gives a completed questionnaire from a manufacturing company:

Table 3 - Completed questionnaire

S/N	Indicators	Company A
	Note: Yes = 1, No =0	
A	**Wellbeing**	
1	Is your Frequency Rate (FR) – Number of recordable incidents per 1 million man-hours worked/year less than the national average	1
2	Is your Severity rate (SR) – Number of man days lost per 1million man-hours worked/year - less than the national average	1
3	Do you have atleast one Health and wellness programs in 1 year	1
4	At least 50% of employee satisfied	0
5	Are the Safety and health arrangements for employee adequate	1
B	**Resource**	
6	Does the company subscribe to adoption to 3R principles	0
7	Dos the company voluntarily subscribe to Disclosure of Greenhouse Gas (GHG)	0

	emissions from own operations as per ISO 14064	
8	Is there any commitment to reduce CHG emissions with timelines. This is over and above the legal limits of emission for CHG	1
9	System Energy efficiency meet regulatory requirements	1
10	Is the Waste diversion rate greater than 1, which otherwise would have gone to landfill	1
C	**Compliance**	
11	In your employment practices, Child and Forced Labour is abolished	1
12	In your employment practices, there is no Employee discrimination	**1**
13	Do you engage with any interested and social groups	1
14	Is the company 100% compliant to legal and other applicable requirements such as REACH, RoHS, WEE and other international environmental regulations	1
15	Do you use of ODS - banned under Montreal Protocol.	1
D	**Management System**	
16	Are you certified to ISO 14001 management system	1
17	Are you certified to ISO 50001/SS 564 management system	1
18	Are you certified to Certified to LEED/ Green Buildings	0
19	Are all your employees competent	1
20	Do you conduct Environment and Energy Audit atleast once a year	**1**

Based on the above data collected for Company A, following table 4 shows the score obtained in different constructs:

Table 4 - .Scoring for each construct of sustainability by each company

S/N	Indicators	Company. A
A	Wellbeing	4
B	Resource	3
C	Compliance	5
D	Management System	4

Substituting these values in Equation 2, we get

SI = (0.375*4+0.25*3+0.25*.5+0.125*4)/5 = 0.8 or 80% .... Equation 3

Thus we can see the Sustainability Index for Company A is 80%. Similar computation can be made for other company and data can be benchmarked

It can be observed from the above study, detailed sub constructs could be ascertained to make the scoring more comprehensive as mentioned in Table 6 below. This would enable to get the scoring finer with more details and be able to reflect the Sustainability Index (SI) in a holistic approach

Table 5 - Sub components for the four constructs

S/N	**Indicators**	**Sub Criteria**
1	Compliance to REACH, RoHS, WEE and other international environmental regulations	• Compliance 100% • 50-99%

		• No compliance
2	Use of ODS - banned under Montreal Protocol.	• No usage • Usage but committed to phase out • Usage
3	Adoption to 3R principles	• Adoption of 3R • Adoption of 2R • Adoption of 1R • Committed to adopt 3R • No principles
4	Disclosure of GHG emissions from own operations as per ISO 14064	• Disclosed • Voluntary/internal disclosure • No disclosure
5	Commitment to reduce CHG emissions with timelines. This is over and above the legal limits of emission for CHG	• >50% • 16-49% • 1-15% • 0%
6	Treatment of waste	• Treatment to comply law • Waste manifest available • No treatment
7	Waste diversion rate, which otherwise would have gone to landfill	• >75% • 51-75% • 26-50% • 1-25% • 0 %
8	Use of recycled materials like paper, and chemicals	• in 1st year – usage >25% • 16-24% • 10-15% • 1-9% • 0%
9	Renewable and alternate energy usage as a percentage of total energy	• in 1st year: • >50% • 26-50% • 10-25% • 1-9% • 0 %
10	Energy Audit – conducted in the year. Conducted and implemented recommendations	• once a year • Once in 2 years • once in 3 years • Never conducted
11	Use of child/forced labor	• Yes • Partially • No -
12	Compliance to legal and the requirements	• Fully • Partially • Sometimes • No
13	Subscription to CSR as per EICC code	• Yearly once

		• Semi annual • Monthly • Weekly • None
14	Engagement with interested parties/social groups	• Once • More than once • Never
15	Discrimination against rave, color, gender,	• Fully • Partially • Sometimes • No
16	Accident frequency rate	• <50% of the national average • <50% of the industrial average • Equal or above 50% of the national average • Equal or above 50% of the industrial average • >100% of any one
17	Loss time injury rate	• <50% of the national average • <50% of the industrial average • Equal or above 50% of the national average • Equal or above 50% of the industrial average • >100% of any one
18	Accident severity rate	• <50% of the national average • <50% of the industrial average • Equal or above 50% of the national average • Equal or above 50% of the industrial average • >100% of any one
19	Sick leave reported	• >50% staff with zero sick leave • 25-49% with zero sick leave • 10-24% with zero sick leave • 1-9% with zero sick leave • 0% with zero sick leave
20	Health and safety programs	• 1 program per month • 1 program per quarter • 1 program per half year • 1 program in a year • No program
21	ISO 14001 management system – Certification	• Certified and current • Under process • Certified but expired • No certification
22	OHSAS 18001 management system Certification	• Certified and current • Under process • Certified but expired • No certification

23	ISO 50001 management system or equivalent Certification such as SS 564	• Certified and current • Under process • Certified but expired • No certification
24	Certified LEED/ Green Buildings	• International • Local • Voluntary disclosure • Under process/committed • No certifications
25	Training/Education and competency	• 100% staff trained • 51 -99% • <50%

IV. CONCLUSION

The broad parameters on sustainability indicators were obtained. Based on the raw datasets obtained for the four latent constructs, the Sustainability framework was established. Using a combination of weightage factor and relative scoring, Sustainability index was computed for one manufacturing plant in Singapore. Similar model will be used to establish sustainability index for other semiconductor plants and subsequently to benchmark against each other. Using this model, benchmarking in SI can be computed for any industrial sector

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Sustainability Index benchmarking in a Semiconductor Manufacturing Environment

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Abstract. Sustainability is becoming an important tool towards our better future. More and more companies are looking into sustainability as their prime focus. Sustainability encompasses responsibilities towards social, energy, water, pollution and economic factors. Sustainability is the ability to sustain. Sustainability Index evaluation criteria and checklist has been created for a typical semiconductor manufacturing industries and the sustainability index has been compared with similar industry. Based on the benchmarking conducted for two plants one of them ranked at 75% indicating high on sustainability index. Benchmarking on sustainability index is a useful measure for shareholders, customers and employees.

Introduction

A universally accepted definition of sustainability is elusive at this point. Sustainability is more than just an internal reform movement. It has created a bridge between business and green [1]. It was noted during the 2005 World Summit, the pillars of sustainability are environmental, social and economic demands. The UK Coalition Government refreshed vision and commitments for sustainable development build on the principles that underpinned the UK's 2005 sustainable development strategy, by recognizing the needs of the economy, society and the natural environment, alongside the use of good governance and sound science [2]. The concept of sustainable development emerged from the post-War environmental movement, which recognized the negative impacts of human growth and development on the environment and communities. Since publishing the first ever national strategy for sustainable development in 1994, the UK Government has played a lead role in promoting sustainable development at home and overseas. Sustainability is the capacity to endure. Sustainability economics involves ecological economics where social, cultural, health-related and monetary/financial aspects are integrated. Moving towards sustainability is also a social challenge that entails international and national law, urban planning and transport, local and individual lifestyles and ethical consumerism. The most widely accepted and at the same time challenged method of measuring sustainability refers to the use of Sustainability Indicators [3]. Environmental benchmarking tools include company-oriented eco-labels, green accounting, life-cycle assessment, product-oriented eco-labels and environmental product declarations. Business must take the lead in directing the earth away from collapse, and towards sustainability and restoration. International green building certifications like LEED [4,5] considers sustainable sites as one of the elements of the certification and considers storm water management, heat island, visual pollution, water use for irrigation, onsite renewable energy. Dow Jones uses the NASDAQ - Global Sustainability Index have taken a leadership role in disclosing their carbon footprint, energy usage, water consumption, hazardous and non-hazardous waste, employee safety, work force diversity, management composition and community investing [6]. Sustainable supply chain management consists of environmental performance, economic performances and social performance [7].

There is an urgent need to integrate environmental performances, energy and material resource conservation and occupational health and safety performance, as a whole referred as sustainability. Present paper attempts to benchmark Sustainability Index (SI) within semiconductor-manufacturing environment.

Semiconductor industry uses large quantities of energy and water and uses many toxic and greenhouse gases in the processes. These plants also generate high volume of waste. Semiconductor fabrication plants produce different products of wafers and chips in a highly clean room environment. Some of the variables in wafer chip production are wafer size (usually 8” or 12” in diameter of the wafer), wafer junction modes, (usually in nanometers), wafer usage (usually memory), wafer production capacity (in thousands of wafer per month), wafer area (in square millimeters per chip) and clean room manufacturing area (size of the clean room). Thus benchmarking has to be on a common factor and this study compares the sustainability performance of the plant based on wafer size of 200 mm (or 8” diameter wafers). Other variables of the wafer are not considered for this study.

Sustainable Computation

Literature survey was done to study the type and extent of indicators used to benchmark semiconductor industry for sustainability. Secondary data sources were from direct interaction with process and facilities professionals from the industry and academia in Singapore. For an organization to be sustainable, the organization need to take care of the wellbeing of their working capital, preserve and conserve resources, have corporate governance and social responsibility and have sound management system. After careful understanding of the sustainability and indexing sustainability, indicators for sustainability should have five elements. It is important to understand as what indicators are to be considered for sustainability indexing. These five elements are:

a. Safety and Health – indicate the welfare, social factors of the organizations
b. Environment Protection – represent direct sustainability indicator
c. Resource conservation – represent the aspect of conserving environment and energy
d. Local legal compliance and Corporate social responsibility – represent direct corporate governance and social responsibility
e. Management system – Represent the indicator as how good the organization is managed.

Consideration for sub-elements for the above elements was carefully evaluated. In the process of evaluating the Sustainability Index of an organization, a set of questionnaire in the form of worksheet or evaluation criteria was prepared (Table 1). Data are collected from the sample two semiconductor companies and were used to complete the worksheet.

Table 1 Sustainable Index Evaluation

S/N	Indicators	Criteria	Basis Points	Plant1	Plant 2
A	**Safety and Health**				
1	Frequency Rate (FR) – Number of recordable incidents per 1 million man-hours worked per year	Zero FR Below country rate Above country rate Fatality (at least 1)	5 3 1 0	5	3
2	Severity rate (SR) – Number of man days lost per 1 million man-hours worked/year	Zero SR SR below country rate SR above country rate Fatality (at least 1)	5 3 1 0	5	3
3	Health and wellness programs	Yes No	5 0	5	5
B	**Environment Protection**				
4	Compliance to REACH, RoHS, WEE and other international environmental regulations	Compliance 100% 50-99% No compliance	5 2 0	5	5
5	Use of ODS - banned under Montreal Protocol.	No usage Usage but committed to phase out Usage	5 2 0	5	5

6	Adoption to 3R principles	Adoption of 3R Adoption of 2R Adoption of 1R Committed to adopt 3R No principles	5 3 2 1 0	3	5
7	Disclosure of GHG emissions from own operations as per ISO 14064	Disclosed Voluntary/internal disclosure No disclosure	5 3 0	3	0
8	Commitment to reduce CHG emissions with timelines. This is over and above the legal limits of emission for CHG	>50% 16-49% 1-15% 0%	5 3 2 0	2	3
9	Treatment of waste	Treatment to comply law Waste manifest available No treatment	5 1 0	5	5
C	**Legal & CSR**				
10	Child and Forced Labor	No forced/child labor Known forced or child labor - 0	5 0	5	5
11	Employee discrimination	No employee discrimination Known at least one case	5 0	5	5
12	Engaging interested and social groups	Yes No	5 0	5	5
D	**Resource Conservation**				
13	Waste diversion rate, which otherwise would have gone to landfill	>75% 51-75% 26-50% 1-25% 0 %	5 4 3 1 0	3	1
14	Use of recycled materials like paper, and chemicals	in 1st year – usage >25% 16-24% 10-15% 1-9% 0%	5 3 2 1 0	2	3
15	Renewable and alternate energy usage as a percentage of total energy	in 1st year: >50% 26-50% 10-25% 1-9% 0 %	 5 3 2 1 0	0	0
16	Energy Audit – conducted in the year. Conducted and implemented recommendations	once a year Once in 2 years once in 3 years Never conducted	5 2 1 0	5	2
E	**Management System**				
17	ISO 14001 management system – Certification	Certified and current Under process Certified but expired No certification	5 2 1 0	5	2
18	OHSAS 18001 management system Certification	Certified and current Under process Certified but expired No certification	5 2 1 0	2	2
19	Certified LEED/ Green Buildings	International Local Voluntary disclosure Under process/committed No certifications	5 3 2 1 0	0	0
20	Training/Education and competency	100% staff trained 51 -99% <50%	5 2 0	5	2
		TOTAL (SI)	**100 (MAX)**	**75**	**60**

It should be noted that not all elements are given equal weightage. In terms of priority, environment protection is given the highest weightage, while resource conservation and management system are given medium weightage and corporate social responsibility and safety and health issues are given relatively low weighatge. Once the table is completed, and scoring for each organization is computed.

In a scale of 100 points, the organization scoring greater than 95 percent is perceived to be highly sustainable. As a general rule, Rating based on the sustainability index scoring can be made as highlighted in Table 2. The rating and the sustainability index of the two companies are compared.

Table 2 Sustainable Index Rating

SI levels	<50%	50-74%	75-94%	>95%
Rating	LOW	MEDIUM	HIGH	EXCELLENT

Analysis and Discussion

The data for the two semiconductor manufacturing plant were compared for the Sustainability Index (SI). It was observed from the table, Plant 1 is rated better than Plant 2. Advantage of these benchmarking provides employers an opportunity to improve on the system and be corporate and socially responsible. As can be seen from the data, Plant 1with a sustainable index of 75% can be qualified for 'High Sustainable Index' rating, while Plant 2 with an index score of 60% will be classified as 'Medium Sustainable index' rating. Economic indicators were not considered for this study due to its complexity.

Advantage of the sustainability index computation and benchmarking will be helpful for shareholders, regulatory agencies, insurance agencies, employees, and customers. This benchmarking can also be used a marketing tool, subject to confidentiality and other agreements. Further the benchmarking of the sustainability index will help organization to improve on the scores and a typical plan-do-check-act methodology can be adopted for continual improvements. Economic indicators were not considered for this study due to its complexity.

Conclusions

By obtaining the Sustainability Index (SI) for a semiconductor manufacturing plant, it is possible to benchmark with each other and conclude as which one is more sustainable. This method of benchmarking can be extended across the country and industry. Other parameters like economic indicators, manpower deployment and wafer size can be extended for the benchmarking study. Caution however is required as benchmarking is good only when companies of equal product lines are compared.

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